Is Impervious Cover Still Important? Review of Recent Research

Thomas R. Schueler[1]; Lisa Fraley-McNeal[2]; and Karen Cappiella[3]

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DOI: 10.1061/(ASCE)1084-0699(2009)14:4(309)

CE Database subject headings: Streams; Urban areas; Urban development; Watersheds.

Introduction

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Schueler (2004) has utilized IC to classify and manage urban streams, and economists routinely use IC to set rates for storm-water utilities and off-site mitigation (Parikh et al. 2005). Engineers utilize IC as a key input variable to predict future downstream hydrology and design storm-water management practices (MSSC 2005). A number of localities have modified their zoning to establish site-based or watershed-based IC caps to protect streams or drinking water supplies. In recent years, IC has been used as a surrogate measure to ensure compliance with water quality standards in impaired urban waters (Bellucci 2007).

Another noteworthy aspect of IC has been its use as an index of the rapid growth in land development or sprawl at the watershed, regional, and national scale. For example, Jantz et al. (2005) found that IC increased at a rate five times faster than population growth between 1990 and 2000 in the Chesapeake Bay watershed. At a national level, several recent estimates of IC creation underscore the dramatic changes in many of our nation's watersheds as a result of recent or future growth. Elvidge et al. (2004) estimated that about 112,665 km^2 (43,500 mi^2) of IC had been created in the lower 48 states as of 2000. Forecasts by Beach (2002) indicate that IC may nearly double by the year 2025 to about 213,837 km^2 (82,563 mi^2), given current development trends. Although care must be taken when extrapolating from national estimates, it is clear that several hundred thousand stream miles are potentially at risk. For example, a detailed GIS analysis by Exum et al. (2006) indicates that 14% of the total watershed area in eight southeastern states had exceeded 5% IC as of 2000.

Given growth in IC, watershed managers are keenly interested in the relationship between subwatershed IC and various indicators of stream quality. The impervious cover model (ICM) was first proposed by Schueler (1994) as a management tool to diagnose the severity of future stream problems in urban subwatersheds. The ICM projects that hydrological, habitat, water quality, and biotic indicators of stream health decline at around 10% total IC in small (i.e., 5 to 50 km^2) subwatersheds (CWP 2003). The ICM defines four categories of urban streams based on how much IC exists in their contributing subwatershed: *sensitive, impacted, nonsupporting,* and *urban drainage* (Schueler 1994) (Fig. 1). The ICM also outlines specific quantitative or narrative predictions for stream indicators within each stream category to define the severity of current stream impacts and the prospects for their future restoration (Schueler 2004).

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Abstract: The impervious cover model (ICM) has attracted considerable attention in recent years, with nearly 250 research studies testing its basic hypothesis that the behavior of urban stream indicators can be predicted on the basis of the percent impervious cover in their contributing subwatershed. The writers conducted a meta-analysis of 65 new research studies that bear on the ICM to determine the degree to which they met the assumptions of the ICM and supported or did not support its primary predictions. Results show that the majority of research published since 2003 has confirmed or reinforced the basic premise of the ICM, but has also revealed important caveats and limitations to its application. A reformulated conceptual impervious cover model is presented in this paper that is strengthened to reflect the most recent science and simplify it for watershed managers and policy makers. A future challenge is to test the hypothesis that widespread application of multiple management practices at the catchment level can improve the urban stream degradation gradient that has been repeatedly observed by researchers across the country.

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Introduction

Impervious cover (IC) has unique properties as a watershed metric in that it can be measured, tracked, forecasted, managed, priced, regulated, mitigated, and, in some cases, even traded. In addition, IC is a common currency that is understood and applied by watershed planners, storm-water engineers, water quality regulators, economists, and stream ecologists alike. IC can be accurately measured using either remote sensing or aerial photography (Goetz et al. 2003; Jantz et al. 2005). IC is also strongly correlated with individual land use and zoning categories (Cappiella and Brown 2001; Slonecker and Tilley 2004), which allows planners to reliably forecast how it changes over time in response to future development. Consequently, watershed planners rely on IC (and other metrics) to predict changes in stream health as a consequence of future development (CWP 1998).

Schueler (2004) has utilized IC to classify and manage urban streams, and economists routinely use IC to set rates for storm-water utilities and off-site mitigation (Parikh et al. 2005). Engineers utilize IC as a key input variable to predict future downstream hydrology and design storm-water management practices (MSSC 2005). A number of localities have modified their zoning to establish site-based or watershed-based IC caps to protect streams or drinking water supplies. In recent years, IC has been used as a surrogate measure to ensure compliance with water quality standards in impaired urban waters (Bellucci 2007).

Another noteworthy aspect of IC has been its use as an index of the rapid growth in land development or sprawl at the watershed, regional, and national scale. For example, Jantz et al. (2005) found that IC increased at a rate five times faster than population growth between 1990 and 2000 in the Chesapeake Bay watershed. At a national level, several recent estimates of IC creation underscore the dramatic changes in many of our nation's watersheds as a result of recent or future growth. Elvidge et al. (2004) estimated that about 112,665 km^2 (43,500 mi^2) of IC had been created in the lower 48 states as of 2000. Forecasts by Beach (2002) indicate that IC may nearly double by the year 2025 to about 213,837 km^2 (82,563 mi^2), given current development trends. Although care must be taken when extrapolating from national estimates, it is clear that several hundred thousand stream miles are potentially at risk. For example, a detailed GIS analysis by Exum et al. (2006) indicates that 14% of the total watershed area in eight southeastern states had exceeded 5% IC as of 2000.

Given growth in IC, watershed managers are keenly interested in the relationship between subwatershed IC and various indicators of stream quality. The impervious cover model (ICM) was first proposed by Schueler (1994) as a management tool to diagnose the severity of future stream problems in urban subwatersheds. The ICM projects that hydrological, habitat, water quality, and biotic indicators of stream health decline at around 10% total IC in small (i.e., 5 to 50 km^2) subwatersheds (CWP 2003). The ICM defines four categories of urban streams based on how much IC exists in their contributing subwatershed: *sensitive, impacted, nonsupporting,* and *urban drainage* (Schueler 1994) (Fig. 1). The ICM also outlines specific quantitative or narrative predictions for stream indicators within each stream category to define the severity of current stream impacts and the prospects for their future restoration (Schueler 2004).

The general predictions of the ICM are as follows: streams with less than 10% subwatershed IC continue to function as *sensitive streams*, and are generally able to retain their hydrologic

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